BUFFERS

The Case of the Mortified Mom

Part I: Evening at the Matthews

Sarah Mathews, an accountant, is sitting with her husband Tom having their after-dinner coffee, and asks, “Another cup, honey?” “No thanks; more than one seems to bother me these days, especially this late in the evening.” Sarah is about to express her concern when their son Paul, a high school junior, bursts in and says, “Mom, and Dad! Do you know what the pH is of that coffee you’re drinking?” “What’s pH?” asks Tom. “C’mon Dad, it’s a measure of acidity—and coffee is like a pH of 5!”

“So, what does that mean, and will it hurt me? Don’t we eat other acid things?” responds Tom. At this point, Sarah interjects, “But I thought that neutral solutions, like plain water, are pH 7, which doesn’t seem like very far away from 5 to me ….” “Yeah, right, Mom; pH 5 is only 100-times more acidic than water. Or try that vinegar we put in our homemade salad dressing—it’s around pH 3, 100 times more acidic than this coffee is!”

His dad asks, “I don’t get it. How can only two units, like the difference between 3 and 5, or 5 and 7, give you 100 times as much?” “’Cause, Dad, it’s a log scale—you know, like earthquakes—and the 2 units mean 2 powers of 10, like 10 squared; that’s where the 100 comes from!” Sarah chimes in (she is better at math than Tom), “So you mean if there were 3 pH units difference, that would be 10 cubed, or 1000 times? And if you went from pH 3.7 to pH 6.7, that would also be 1000-fold?”

“Now you’re getting it! And here is the cool trick we learned today: just like 1.0 pH unit is a factor of 10 in acidity, 0.3 pH units is a factor of 2!” “Whoa, slow down, Paul,” replies Tom, “you’ve got my head spinning now. Besides, it’s getting late and you have school tomorrow, so off to bed with you!” [Unlike Tom, you have followed this perfectly, and can do the assigned practice problems without a calculator.]

Part II: The Next Day

The next day brought a beautiful fall afternoon, and the maples were just starting to show their autumn colors. Sarah was enjoying her long late afternoon run and was only a few blocks away from home when she was surprised by the ringtone of her phone.

“Mom, it’s Paul! Get home quick! I was on the computer downstairs, so I didn’t hear Molly fall down in your bathroom—even though she’s only 3, she must have managed to climb onto the toilet seat, then the sink, and reach up to the medicine cabinet. She must have thought the pills in there were candy, and I think she started eating a whole bunch of aspirin tablets before she fell! Anyway, I finally heard her crying, and went upstairs where I found her curled up and whimpering on the bathroom floor, with colored pills and cracked bottles scattered around. I don’t think she broke anything, but it looks like she threw up. Oh, no! She just threw up again, this time on me! Hurry, Mom!”

Sarah immediately called 911 for an ambulance, then shifted her running into high gear, since Tom was at work across town. Fueled by adrenalin, Sarah essentially sprinted the rest of the way home, her mind racing as her heart pounded, her lungs ached, and her legs burned from the effort. She berated herself for leaving Molly alone with Paul, not fixing the recently broken latch on the medicine cabinet, and being so far from home without a car. She didn’t know how many tablets of aspirin Molly had consumed, but had recently read that a fatal dose for a child could be as little as 3 grams (10 300-mg tablets). By the time she arrived home a few minutes later, Molly seemed sleepy, almost lethargic, and Paul said she had vomited several times. Sarah thought that was good, since bits of undissolved tablets could be seen—but just then the ambulance arrived, and after briefly checking Molly’s status, they rushed her to the nearby hospital’s Emergency Room.

Symptoms and Examination

Sarah Mathews arrived at the Emergency Room with her daughter Molly, where the little girl immediately underwent a physical exam and lab samples were obtained for analysis. By this time, she was almost unarousable, and was breathing rapidly and deeply. The physician on duty, Dr. Pedro Martinez, intubated Molly's trachea for airway protection and carried out hyperventilation, which he said was "to avoid hypoventilation and a worsening of her metabolic acidosis."

"What does that have to do with aspirin?" asked Sarah, anxiously.

Dr. Martinez replied, “Well, aspirin was originally a trademark for acetosalicylic acid, which can inhibit a pathway, leading to inflammation, but it is also a weak organic acid. That means at high levels it can lower the pH of your blood from its normal value of about 7.4—and any level below about 7 begins to be dangerous. As you can see, the nurse is also starting to administer activated charcoal through a nasogastric tube to absorb any residual aspirin in Molly’s stomach and prevent its entry into the bloodstream.”

“Oh,” said Sarah, “Our son Paul was trying to explain pH to my husband and me last night—but what do you mean by dangerous, and what can you do to get it back up again?”

They were interrupted by another nurse who came in with lab results. Dr. Martinez frowned as he looked over the results. They revealed a pH of 6.8 and a plasma salicylate level of 100 mg/dL, together with a number of other electrolyte abnormalities. He hadn’t seen a pH that low for some time. It certainly explained Molly’s rapid and deep respiration.

Question #1

- By what factor does the [H+] of Molly's blood (pH 6.8) differ from normal (pH 7.4)?
  (A) 0.25x
  (B) 0.5x
  (C) 0.6x
  (D) 2.0x
  (E) 4.0x
- Remember that every factor of 10 difference in $[H^+]$ represents 1.0 pH units, and every factor of 2 difference in $[H^+]$ represents 0.3 pH units.

Molly’s Problem is…

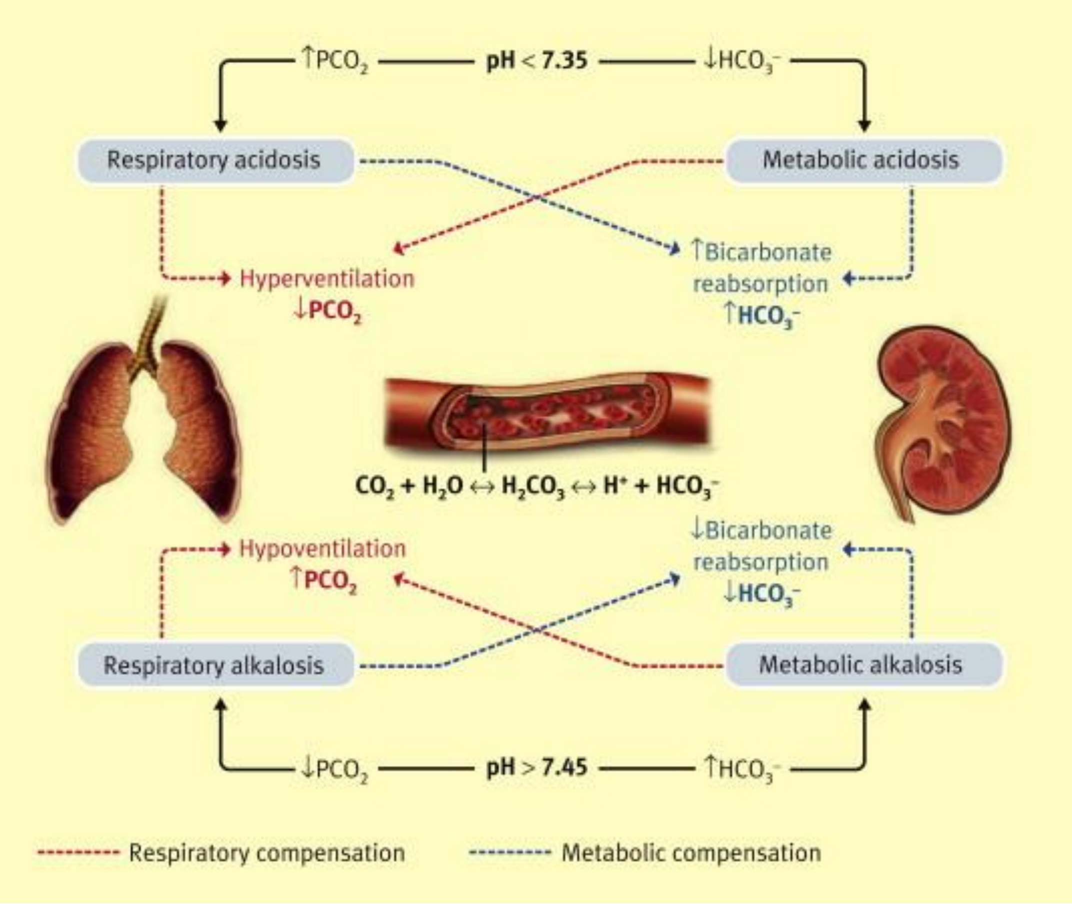
- She has ingested far too much aspirin, i.e., acetylsalicylic acid (a weak acid), which has brought her to the Emergency Room

- The window of pH within which humans can survive is between a blood value of about pH 6.8 to around pH 8.0

- Outside that range brings coma and death thus rapid treatment for Molly is crucial

Human Body and pH

- pH is determined by the amount of H^+ in the blood
  - Controlled by reaction of CO_2 into HCO_3^- and vice versus



Question #2

- Why is Molly breathing so rapidly and deeply when she arrives at the Emergency Room, despite being nearly comatose?

(A) The aspirin has inhibited her ability to use oxygen effectively.

(B) Her body is trying to rid itself of CO_2.

(C) She is out of breath from all she has been through.

(D) Her hemoglobin can’t deliver oxygen at low pH.

Molly’s Self Defense

- Molly’s heavy breathing isn’t helping very much. Why?
  - Think about the aspirin in her bloodstream and the equilibrium between its acid (undissociated) and its dissociated form.
  - As protons are removed from solution by her heavy breathing, is there a reservoir of others to take their place…?

$$CO_2 + H_2O \rightleftharpoons H_2CO_3^- \rightleftharpoons H^+ + HCO_3^-$$

Treatment

The doctor immediately ordered emergency treatment with intravenous bicarbonate (to correct the systemic acidosis), hydration (fluid replacement to compensate for Molly's vomiting), and hemodialysis (to correct electrolyte imbalance and remove dissolved salicylate—aspirin—from her body).

He continued with his explanation to Sarah, "We use bicarbonate—the same compound as in baking soda—as a 'buffer,' that is, a substance that can combine with the 'acid' ions (which, you may know, are protons in solution), thus soaking them up to reduce the acidity and raise the pH. One of the good things about bicarbonate is that it is a 'natural' substance."

“Your body in fact normally has moderate amounts of bicarbonate all the time, and that is how the CO_2 produced in your tissues by metabolism is transported to your lungs to be exhaled. In fact, bicarbonate is produced whenever you dissolve carbon dioxide in water, but hydrogen ions are also produced, which makes the solution more acidic. I can show you the simple formula indicating the chemical equilibrium, or perhaps you’d like to ask your son Paul to do it?”

They saw that Molly’s breathing was returning to a more normal rate, and breathed a collective sigh of relief. “She’s out of danger now, but we’ll keep a close eye on her for a while yet,” said Dr. Martinez.

Explanations

Sarah, however, still curious, asked, “So does that mean when you remove CO_2 from a solution, it becomes less acidic and the pH goes back up?” “Gee, Mrs. Mathews,” replied Dr. Martinez, “you’d make a terrific chemist!” “And that’s why Molly’s breathing was that way? Her body was trying to raise its pH by getting rid of as much CO_2 as it could, even though it didn’t really help much, because the problem was all that aspirin, which she couldn’t get rid of!”

The doctor answered, “Yes, and in medical terminology we call that the difference between metabolic acidosis, which is Molly’s problem—lots of acidic compounds in her bloodstream—and respiratory acidosis, which can occur if too much dissolved CO_2 builds up there.” “But that must mean that in your tissues, where metabolism is going on and resulting in all that CO_2 and water, the pH is lower than in your lungs, where your body is getting rid of CO_2! Is that why my leg muscles got so sore after my 10-minute sprint home this afternoon—though I’ve always heard it is from lactic acid buildup?”

Dr. Martinez answered, “Well, you’re correct on the first count, and the low pH from the lactic acid, not from CO_2, is the problem in the second instance—but my pager is going off , and I have to rush over to check on another patient. Molly will be fine, but don’t hesitate to give me a call if you have any further questions—and fix that latch on your medicine cabinet!”

Buffers

- Buffered solution—one that resists a change in its pH when either hydroxide ions or protons are added
- Can be created in multiple different ways

Components	Examples
Weak acid + salt containing conjugate base	HCN and NaCN
Weak base + salt containing the conjugate acid	CH_3NH_2 and CH_3NH_2Cl
Weak acid + excess strong base	HCN and NaOH react to give HCN and NaCN
Weak base + excess strong acid	NH_3 and HCl react to get NH_3 and NH_4Cl

Calculations Involving Buffers

- Four types of calculations can be performed with buffers:
  (1) Calculation of pH of a buffer
  (2) Preparation of a buffer
  (3) Addition of strong acid to a buffer
  (4) Addition of strong base to a buffer

Calculating pH of a Buffer

- Similar to other pH calculations except now there are two initial concentrations

- Example #1: Calculate the pH of a solution that is 0.60 M HF and 1.0 M KF. K_a for HF is 7.2×10^{-4}.

Preparation of a Buffer

- Can be made from a weak acid and a salt containing its conjugate base or a weak base and a salt containing its conjugate acid
- Henderson-Hasselbalch relationship

$$pH = pK_a + \log\left(\frac{[base]}{[acid]}\right)$$

- $pK_a = -\log K_a$

- Example #2: Calculate the mass of $NaC_2H_3O_2$ required to prepare a buffer of pH 4.55 when added to 0.500 L of 0.67 M acetic acid, assuming no change in volume. K_a for acetic acid is 1.8×10^{-5}.

Addition of Strong Acid/Base to a Buffer

- Calculations can be performed to determine how the addition of a strong acid or base will affect the pH of a buffer

- Example #3: Calculate the pH when 100.0 mL of 0.50 M HCl are added to the buffer consisting of 20.0 g of $HC_2H_3O_2$ and 18.0 g of $NaC_2H_3O_2$ dissolved in 500 mL of water.

- Example #4: Calculate the pH when 100.0 mL of 0.50 M NaOH are added to the buffer consisting of 20.0 g of $HC_2H_3O_2$ and 18.0 g of $NaC_2H_3O_2$ dissolved in 500 mL of water.

References

- Terry Platt, “Acids, pH, and Buffers: Some Basic Chemistry for Biological Science” (http://sciencecases.lib.buffalo.edu/cs/collection/detail.asp?case_id=498&id=498)